PB-239 576

LAKE DARLING, DOUGLAS COUNTY, MINNESOTA

Pacific Northwest Environmental
Research Laboratory

Prepared for:

National Environmental Research Center
Minnesota Pollution Control Agency

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16. ABSTRACT
Annual total phosphorus and total nitrogen loadings to the lake were estimated and subdivded according to either point or non-point source origin. An assessment of the lake's trophic condition and limiting nutrient is also provided. All data collected by the U.S.E.P.A. National Eutrophication Survey during the one year study of the lake and its tributaries are included in the report.

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FOREWORD

The National Eutrophication Survey was initiated in 1972 in response to an Administration commitment to investigate the nationwide threat of accelerated eutrophication to fresh water lakes and reservoirs.

OBJECTIVES

The Survey was designed to develop, in conjunction with state environmental agencies, information on nutrient sources, concentrations, and impact on selected freshwater lakes as a basis for formulating comprehensive and coordinated national, regional, and state management practices relating to point-source discharge reduction and non-point source pollution abatement in lake watersheds.

ANALYTIC APPROACH

The mathematical and statistical procedures selected for the Survey's eutrophication analysis are based on related concepts that:

a. A generalized representation or model relating sources, concentrations, and impacts can be constructed.

b. By applying measurements of relevant parameters associated with lake degradation, the generalized model can be transformed into an operational representation of a lake, its drainage basin, and related nutrients.

c. With such a transformation, an assessment of the potential for eutrophication control can be made.

LAKE ANALYSIS

In this report, the first stage of evaluation of lake and watershed data collected from the study lake and its drainage basin is documented. The report is formatted to provide state environmental agencies with specific information for basin planning [§303(e)], water quality criteria/standards review [§303(c)], clean lakes [§314(a,b)], and water quality monitoring [§106 and §305(b)] activities mandated by the Federal Water Pollution Control Act Amendments of 1972.

Beyond the single lake analysis, broader based correlations between nutrient concentrations (and loading) and trophic condition are being made to advance the rationale and data base for refinement of nutrient water quality criteria for the Nation's fresh water lakes. Likewise, multivariate evaluations for the relationships between land use, nutrient export, and trophic condition, by lake class or use, are being developed to assist in the formulation of planning guidelines and policies by EPA and to augment plans implementation by the states.

ACKNOWLEDGMENT

The staff of the National Eutrophication Survey (Office of Research & Development, U. S. Environmental Protection Agency) expresses sincere appreciation to the Minnesota Pollution Control Agency for professional involvement and to the Minnesota National Guard for conducting the tributary sampling phase of the Survey.

Grant J. Merritt, Director of the Minnesota Pollution Control Agency, John F. McGuire, Chief, and Joel G. Schilling, Biologist, of the Section of Surface and Groundwater, Division of Water Quality, provided invaluable lake documentation and counsel during the course of the Survey; and the staff of the Section of Municipal Works, Division of Water Quality, were most helpful in identifying point sources and soliciting municipal participation in the Survey.

Major General Chester J. Moeglein, the Adjutant General of Minnesota, and Project Officer Major Adrian Beltrand, who directed the volunteer efforts of the Minnesota National Guardsmen, are also gratefully acknowledged for their assistance to the Survey.

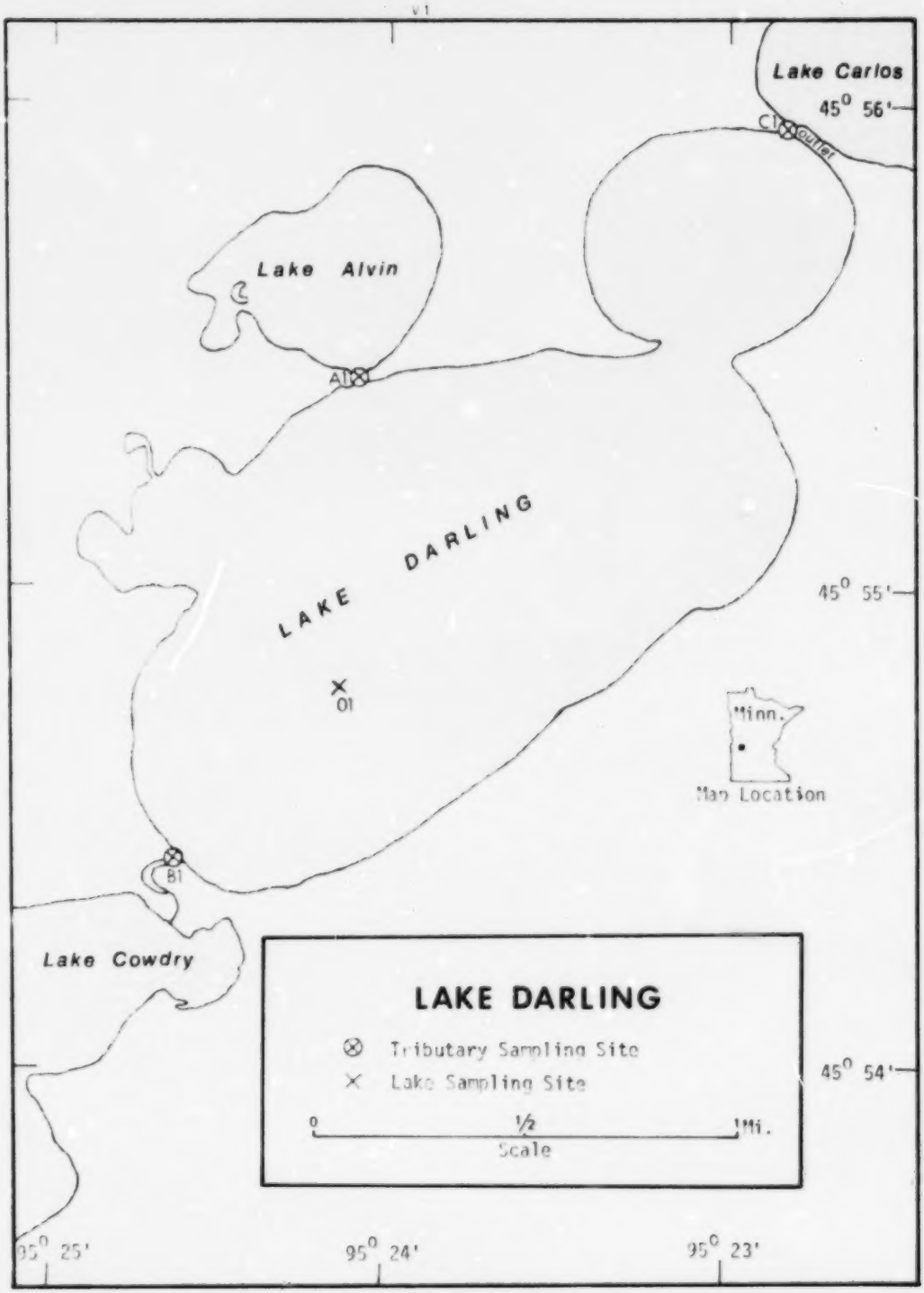
NATIONAL EUTROPHICATION SURVEY

STUDY LAKES

STATE OF MINNESOTA

LAKE NAME	COUNTY
Albert Lea	Freeborn
Andrusia	Beltrami
Badger	Polk
Bartlett	Koochiching
Bear	Freeborn
Bemidji	Beltrami
Big	Stearns
Big Stone	Big Stone, MN; Roberts, Grant, SD
Birch	Cass
Blackduck	Beltrami
Blackhoof	Crow Wing
Budd	Martin
Buffalo	Wright
Calhoun	Hennepin
Carlos	Douglas
Carrigan	Wright
Cass	Beltrami, Cass
Clearwater	Wright, Stearns
Cokato	Wright
Cranberry	Crow Wing
Darling	Douglas
Elbow	St. Louis
Embarass	St. Louis
Fall	Lake
Forest	Washington
Green	Kandiyohi
Gull	Cass
Heron	Jackson
Leech	Cass
Le Homme Dieu	Douglas
Lily	Blue Earth
Little	Grant
Lost	St. Louis

LAKE NAME	COUNTY
Madison	Blue Earth
Malmedal	Pope
Mashkenode	St. Louis
McQuade	St. Louis
Minnetonka	Hennepin
Minnewaska	Pope
Mud	Itasca
Nest	Kandiyohi
Pelican	St. Louis
Pepin	Goodhue, Wabasha, MN; Pierce, Pepin, WI
Rabbit	Crow Wing
Sakatah	Le Sueur
Shagawa	St. Louis
Silver	McLeod
Six Mile	St. Louis
Spring	Washington, Dakota
St. Croix	Washington, MN; St. Croix, Pierce, WI
St. Louis Bay	St. Louis, MN; Douglas, WI
Superior Bay	St. Louis, MN; Douglas, WI
Swan	Itasca
Trace	Todd
Trout	Itasca
Wagonga	Kandiyohi
Wallmark	Chisago
White Bear	Washington
Winona	Douglas
Wolf	Beltrami, Hubbard
Woodcock	Kandiyohi
Zumbro	Olmstead, Wabasha


Lake Carlos
45° 56'
C1
Outlet
Lake Alvin
A1
LAKE DARLING
45° 55'
01
Minn.
Map Location
B1
Lake Cowdry
LAKE DARLING
Tributary Sampling Site
Lake Sampling Site
0
½
1 Mi.
Scale
45° 54'
95° 25'
95° 24'
95° 23'

LAKE DARLING

STORET NO. 27B4

I. CONCLUSIONS

A. Trophic Condition:

Survey data indicate that Lake Darling is meso-eutrophic. Of the 60 Minnesota lakes sampled in the fall when essentially all were well-mixed, six had less mean total phosphorus, three had less mean dissolved phosphorus, but 27 had less mean inorganic nitrogen. Of all 80 Minnesota lakes sampled, only nine had less mean Secchi disc transparency, but 27 had less mean chlorophyll a.

Depression of dissolved oxygen with depth occurred in July, and oxygen was depleted below 25 feet in September.

Reportedly (Schilling, 1974), macrophytes in Lake Darling have been chemically treated for control.

B. Rate-Limiting Nutrient:

There was a differential loss of nutrients in the assay sample from the time of collection to the beginning of the assay, and the results are not indicative of conditions in the lake at the time of sampling.

The lake data indicate nitrogen limitation in July and September but phosphorus limitation in October.

C. Nutrient Controllability:

There are no known point sources impacting Lake Darling, and the entire phosphorus load was from non-point sources.

During the sampling year, the lake received a total phosphorus load at a rate less than the rate proposed by Vollenweider (in press) as "permissible"; i.e., an oligotrophic rate (see page 11).

II. LAKE AND DRAINAGE BASIN CHARACTERISTICS

A. Lake Morphometry†:

1. Surface area: 954 acres.
2. Mean depth: 20.3 feet.
3. Maximum depth: 62 feet.
4. Volume: 19,366 acre-feet.
5. Mean hydraulic retention time: 318 days.

B. Tributary and Outlet:
(See Appendix A for flow data)

1. Tributaries -

Name	Drainage area*	Mean flow*
Lake Cowdry outlet	172.0 mi^2	30.2 cfs
Lake Alvin outlet	0.5 mi^2	0.1 cfs
Minor tributaries & immediate drainage -	1.0 mi^2	0.4 cfs
Totals	173.5 mi^2	30.7 cfs

2. Outlet -

Lake Carlos inlet	175.0 mi^2**	30.7 cfs**

C. Precipitation***:

1. Year of sampling: 22.9 inches.
2. Mean annual: 22.6 inches.

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† DNR lake survey map.
* Drainage areas are accurate within ±5%; mean daily flows are accurate within ±10%; and ungaged flows are accurate within ±10 to 25% for drainage areas greater than 10 mi^2.
** Includes area of lake; outflow adjusted to equal Lake Carlos inflow.
*** See Working Paper No. 1, "Survey Methods".

III. LAKE WATER QUALITY SUMMARY

Lake Darling was sampled three times during the open-water season of 1972 by means of a pontoon-equipped Huey helicopter. Each time, samples for physical and chemical parameters were collected from a number of depths at a single station on the lake (see map, page vi). During each visit, a single depth-integrated (15 feet to surface) sample was taken for phytoplankton identification and enumeration; and a similar sample was collected for chlorophyll a analysis. During the last visit, a single five-gallon depth-integrated sample was composited for algal assays. The maximum depth sampled was 44 feet.

The results obtained are presented in full in Appendix B, and the data for the fall sampling period, when the lake essentially was well-mixed, are summarized below. Note, however, the Secchi disc summary is based on all values.

For differences in the various parameters at the other sampling times, refer to Appendix B.

A. Physical and chemical characteristics:

Parameter	Minimum	Mean	Median	Maximum
		FALL VALUES (10/25/72)		
Temperature (Cent.)	6.4	6.4	6.4	6.4
Dissolved oxygen (mg/l)	10.0	10.6	10.7	11.4
Conductivity (μmhos)	400	409	410	420
pH (units)	8.3	8.4	8.4	8.4
Alkalinity (mg/l)	201	211	216	218
Total P (mg/l)	0.015	0.020	0.017	0.034
Dissolved P (mg/l)	0.008	0.009	0.009	0.013
NO_2 + NO_3 (mg/l)	0.120	0.122	0.120	0.130
Ammonia (mg/l)	0.070	0.073	0.070	0.090
		ALL VALUES		
Secchi disc (inches)	84	101	108	110

B. Biological characteristics:

1. Phytoplankton -

Sampling Date	Dominant Genera	Number per ml
07/06/72	1. Anabaena	1,175
	2. Dinobryon	714
	3. Microcystis	606
	4. Flagellates	262
	5. Coelosphaerium	136
	Other genera	705
	Total	3,598
09/01/72	1. Microcystis	2,025
	2. Lyngbya	1,700
	3. Dinobryon	579
	4. Anabaena	524
	5. Aphanocapsa	452
	Other genera	615
	Total	5,895
10/25/72	1. Fragilaria	942
	2. Dinobryon	885
	3. Anabaena	678
	4. Flagellates	377
	5. Asterionella	264
	Other genera	1,110
	Total	4,256

2. Chlorophyll a -
(Because of instrumentation problems during the 1972 sampling, the following values may be in error by plus or minus 20 percent.)

Sampling Date	Station Number	Chlorophyll a (µg/l)
07/06/72	01	18.2
09/01/72	01	8.6
10/25/72	01	8.7

C. Limiting Nutrient Study:

There was a differential loss of nutrients in the assay sample between the time of collection and the beginning of the assay such that the N/P ratio was shifted from 21/1 in the lake to 11/1 in the sample assay. Consequently, the assay results are not indicative of lake conditions at the time of sampling.

The lake data indicate nitrogen limitation in July (N/P = 8/1) and September (N/P - 11/1) but phosphorus limitation in October (N/P = 21/1).

IV. NUTRIENT LOADINGS
(See Appendix C for data)

For the determination of nutrient loadings, the Minnesota National Guard collected monthly near-surface grab samples from each of the tributary sites indicated on the map (page vi), except for the high runoff months of April and May when two samples were collected and the colder months when low flows prevented sampling at the Lake Alvin outlet. Sampling was begun in October, 1972, and was completed in September, 1973.

Through an interagency agreement, stream flow estimates for the year of sampling and a "normalized" or average year were provided by the Minnesota District Office of the U.S. Geological Survey for the tributary sites nearest the lake.

In this report, nutrient loads for sampled tributaries were calculated using mean annual concentrations and the mean annual flows. Nutrient loadings for unsampled "minor tributaries and immediate drainage" ("ZZ" of U.S.G.S.) were estimated using the means of the nutrient loads, in $lbs/mi^2/year$, in streams tributary to nearby Big Stone Lake at stations 2709D-1, E-1, F-1, and G-1 and multiplying the means by the ZZ area in mi^2.

No known point sources impact Lake Darling.

A. Waste Sources:

1. Known municipal - None

2. Known industrial - None

B. Annual Total Phosphorus Loading - Average Year:

1. Inputs -

Source	lbs P/ yr	% of total
a. Tributaries (non-point load) -		
Lake Cowdry outlet	1,430	88.9
Lake Alvin outlet	10	0.6
b. Minor tributaries & immediate drainage (non-point load) -	20	1.2
c. Known municipal - None	-	-
d. Septic tanks - Unknown	-	-
e. Known industrial - None	-	-
f. Direct precipitation* -	150	9.3
Total	1,610	100.0

2. Outputs -

Lake outlet - Lake Carlos inlet 1,160

3. Net annual P accumulation - 450 pounds

* See Working Paper No. 1.

C. Annual Total Nitrogen Loading - Average Year:

1. Inputs -

Source	lbs N/ yr	% of total
a. Tributaries (non-point load) -		
Lake Cowdry outlet	68,010	87.4
Lake Alvin outlet	240	0.3
b. Minor tributaries & immediate drainage (non-point load) -	370	0.5
c. Known municipal - None	-	-
d. Septic tanks - Unknown	-	-
e. Known industrial - None	-	-
f. Direct precipitation* -	9,190	11.8
Total	77,810	100.0

2. Outputs -

Lake outlet - Lake Carlos inlet 72,600

3. Net annual N accumulation - 5,210 pounds

* See Working Paper No. 1.

D. Mean Annual Non-point Nutrient Export by Subdrainage Area:

Tributary	lbs $P/mi^2/yr$	lbs $N/mi^2/yr$
Lake Cowdry outlet	8	395
Lake Alvin outlet	20	480

E. Yearly Loading Rates:

In the following table, the existing phosphorus loading rates are compared to those proposed by Vollenweider (in press). Essentially, his "dangerous" rate is the rate at which the receiving water would become eutrophic or remain eutrophic; his "permissible" rate is that which would result in the receiving water remaining oligotrophic or becoming oligotrophic if morphometry permitted. A mesotrophic rate would be considered one between "dangerous" and "permissible".

Note that Vollenweider's model may not be applicable to water bodies with very short hydraulic retention times.

	Total Phosphorus		Total Nitrogen	
Units	Total	Accumulated	Total	Accumulated
lbs/acre/yr	1.7	0.5	81.6	5.5
grams/m^2/yr	0.19	0.05	9.1	0.6

Vollenweider loading rates for phosphorus ($g/m^2/yr$) based on mean depth and mean hydraulic retention time of Lake Darling:

"Dangerous" (eutrophic rate)	0.52
"Permissible" (oligotrophic rate)	0.26

V. LITERATURE REVIEWED

Schilling, Joel, 1974. Personal communication (summary of information on Minnesota lakes). MPCA, Minneapolis.

Vollenweider, Richard A. (in press). Input-output models. Schweiz. Z. Hydrol.

TRIBUTARY FLOW INFORMATION FOR MINNESOTA 10/30/74

LAKE CODE 2784 DARLING LAKE

MEAN MONTHLY FLOWS AND DAILY FLOWS

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
2784C1	10	72	53.80	14	90.00				
	11	72	76.80	15	74.00				
	12	72	37.20	15	36.00				
	1	73	16.40						
	2	73	39.50	21	39.00				
	3	73	104.00	13	88.00				
	4	73	104.00	5	130.00	19	98.80		
	5	73	87.90	3	102.00	17	84.00		
	6	73	51.50	8	70.00				
	7	73	41.00	11	39.70				
	8	73	46.00	23	40.50				
	9	73	20.30	30	15.60				
2784Z7	10	72	0.84	14	0.90				
	11	72	0.63	15	0.60				
	12	72	0.43	15	0.40				
	1	73	0.15						
	2	73	0.27	21	0.30				
	3	73	0.95	13	0.80				
	4	73	1.15	5	1.40	19	1.10		
	5	73	1.20	3	1.40	17	1.10		
	6	73	0.90	8	1.00				
	7	73	0.54	11	0.53				
	8	73	0.44	23	0.38				
	9	73	0.33	30	0.27				

12.a

VII. APPENDICES

APPENDIX A

TRIBUTARY FLOW DATA

TRIBUTARY FLOW INFORMATION FOR MINNESOTA 10/30/74

LAKE CODE 27M4 DARLING LAKE

TOTAL DRAINAGE AREA OF LAKE 175.00

TRIBUTARY	SUB-DRAINAGE AREA	JAN	FEB	MAR	APR	MAY	JUN	NORMALIZED FLOWS JUL	AUG	SEP	OCT	NOV	DEC	MEAN
27M4A1	0.66	0.0	0.0	0.26	0.24	0.14	0.24	0.12	0.07	0.06	0.10	0.05	0.02	0.10
27M4B1	172.38	3.00	7.30	22.80	43.50	52.30	58.30	33.30	23.80	12.60	30.10	24.90	6.81	30.15
27M4C1	175.00	3.00	7.60	23.10	44.00	51.10	59.00	33.80	24.10	12.40	30.70	25.30	6.70	30.44
27M4Z7	2.62	0.04	0.05	0.21	0.44	0.73	0.44	0.45	0.23	0.21	0.31	0.21	0.10	0.36

SUMMARY

TOTAL DRAINAGE AREA OF LAKE = 175.00
SUM OF SUB-DRAINAGE AREAS = 175.14

TOTAL FLOW IN = 367.01
TOTAL FLOW OUT = 365.00

NOTE ADJUSTMENT MADE

MEAN MONTHLY FLOWS AND DAILY FLOWS

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
27M4A1	10	72	0.27	14	0.30				
	11	72	0.15	15	0.10				
	12	72	0.09	15	0.04				
	1	73	0.0	12	0.0				
	2	73	0.0	21	0.0				
	3	73	0.27	13	0.20				
	4	73	0.24	5	0.40				
	5	73	0.31	3	0.43				
	6	73	0.24	8	0.40				
	7	73	0.15	11	0.15				
	8	73	0.14	23	0.11				
	9	73	0.09	14	0.07				
27M4B1	10	72	41.20	14	44.00				
	11	72	25.30	15	23.00				
	12	72	17.10	15	16.30				
	1	73	16.65						
	2	73	34.70	8	34.00				
	3	73	103.56	13	88.00				
	4	73	102.30	5	124.00				
	5	73	88.30	4	100.00	10	82.00		
	6	73	60.10	8	64.00				
	7	73	40.30	11	34.10				
	8	73	45.20	23	34.80				
	9	73	14.80	14	14.20				

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APPENDIX B

PHYSICAL and CHEMICAL DATA

STORET RETRIEVAL DATE 74/10/30

27R401
45 44 48.0 095 24 10.0
DARLING LAKE
27 MINNESOTA

11EPALES 2111202
3 0043 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00630 NO2&NO3 N-TOTAL MG/L	00610 NH3-N TOTAL MG/L	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P
72/07/06	11 10	0000			84	340	8.50	198	0.040	0.040	0.017	0.012
	11 10	0004	20.5	9.6		350	8.50	210	0.040	0.060	0.019	0.011
	11 10	0015	20.0	6.8		350	8.50	206	0.030	0.040	0.019	0.008
	11 10	0020	19.0									
	11 10	0022	17.7	4.2		350	8.10	206	0.030	0.040	0.019	0.008
	11 10	0025	11.5									
	11 10	0030	9.8									
	11 10	0042	9.8	1.4		475	7.50	202	0.080	0.240	0.017	0.008
72/09/01	16 00	0000	19.8		110	400	8.05	197	0.060	0.100	0.017	0.007
	16 00	0004	19.9	8.3		380	8.05	194	0.090	0.120	0.015	0.008
	16 00	0010	19.9	8.2		380	8.10	194	0.060	0.090	0.015	0.011
	16 00	0015	19.9	7.6		380	8.10	191	0.090	0.120	0.016	0.012
	16 00	0020	19.9	7.0		380	8.15	190	0.080	0.110	0.016	0.009
	16 00	0025	19.6	7.0		380	8.12	192	0.140	0.180	0.013	0.009
	16 00	0030	15.5	0.0		400	7.40	197	0.140	0.370	0.016	0.007
	16 00	0035	13.1	0.0		407	7.30	203	0.130	0.620	0.036	0.014
72/10/25	16 30	0000			108	420	8.40	202	0.120	0.070	0.017	0.009
	16 30	0004	6.4	11.4		410	8.40	216	0.120	0.070	0.015	0.008
	16 30	0015	6.4	10.8		400	8.40	216	0.120	0.070	0.015	0.008
	16 30	0025	6.4	10.7		410	8.40	218	0.120	0.070	0.017	0.009
	16 30	0035	6.4	10.3		405	8.30	214	0.120	0.070	0.019	0.009
	16 30	0044	6.4	10.0		410	8.30	201	0.130	0.090	0.034	0.013

DATE FROM TO	TIME OF DAY	DEPTH FEET	32217 CHLRPHYL A UG/L
72/07/06	11 10	0000	18.2J
72/09/01	16 00	0000	8.6J
72/10/25	16 30	0000	8.7J

J VALUE KNOWN TO BE IN ERROR

APPENDIX C

TRIBUTARY DATA

STORET RETRIEVAL DATE 74/10/30

27H4A1 LS27H4A1
45 55 30.0 095 24 00.0
LK ALVIN/LK DARLING CONNECTION
27 7.5 ALEXANDRIA W
T/LAKE DARLING
DIRT RD ENDING AT LK CONNECTION
11EPALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/10/14	10	30	0.075	1.350	0.105	0.009	0.072
73/03/13	14	00	0.220	0.980	0.300	0.180	0.210
73/04/05	14	30	0.029	1.900	0.166	0.006	0.020
73/05/03	14	30	0.018	1.050	0.034	0.008	0.020
73/06/08	10	55	0.140	1.380	0.083	0.005K	0.020
73/07/11	14	35		3.600	0.083	0.016	0.030
73/08/23			0.019	1.150	0.025	0.026	0.085
73/09/19	14	30	0.010K	1.260	0.030	0.015	0.060

K VALUE KNOWN TO BE LESS THAN INDICATED

STORET RETRIEVAL DATE 74/10/30

2744H1 LS2744H1
45 54 30.0 095 24 30.0
LK COWDRY/LK DARLING CONN
27 7.5 ALEXANDRIA W
1/LAKE DARLING
CO HWY 22 BRDG NW OF ALEXANDRIA
11EPALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/10/14	10 20		0.038	1.000	0.069	0.005K	0.031
72/11/15	15 45		0.052	0.930	0.048	0.009	0.025
72/12/15	12 40		0.020	0.900	0.046	0.005K	0.016
73/01/12	14 00		0.110	0.940	0.075	0.011	0.020
73/02/21	10 00		0.140	0.930	0.045	0.004	0.030
73/03/13			0.240	0.920	0.068	0.018	0.025
73/04/05	13 45		0.084	2.360	0.056	0.005K	0.020
73/05/03	14 20		0.010K	0.850	0.014	0.009	0.025
73/05/17	14 30		0.014	0.780	0.012	0.005K	0.030
73/06/08	10 55		0.055	0.700	0.042	0.005K	0.020
73/07/11	14 00		0.013	0.960	0.036	0.010	0.020
73/08/23			0.016	1.050	0.037	0.013	0.025
73/09/14	14 15		0.010K	1.400	0.034	0.007	0.025

K VALUE KNOWN TO BE LESS THAN INDICATED